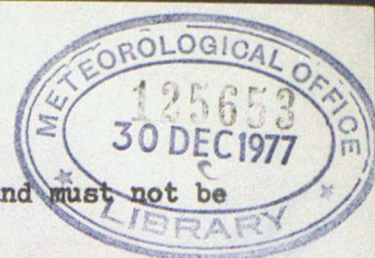


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Agricultural Memorandum No 819

A COMPARISON OF SOIL MOISTURE DEFICITS ESTIMATED FROM NEUTRON PROBE MEASUREMENTS WITH CALCULATIONS FROM METEOROLOGICAL VARIABLES

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SUMMARY

Measurements of soil moisture under grass (see Appendix 1 for botanical composition), at Westbury-on-Trym were made at weekly intervals from April to September 1977 with a Model 225 Wallingford Soil Moisture Probe. Soil moisture deficits deduced from these measurements are compared with deficits calculated from meteorological variables.

NEUTRON PROBE MEASUREMENTS

The use of a neutron probe for measurements of soil water has been described by Long and French 1967. The configuration and use of the Model 225 probe is shown in figure 1. The only departure from normal practice was in the application of corrections to the measurements at shallow depths. These corrections are described in Appendix 2.

METHOD

An access tube was sunk into the soil profile on the meteorological plot at Westbury-on-Trym, Bristol. Weekly readings using the neutron probe were taken to obtain a moisture profile under grass. Counts were recorded at 5 cm stages to a depth of 20 cms, thereafter readings were taken at 10 cm intervals to 70 cms. The soil was assumed to be at field capacity at the end of March 1977, and the sum of the counts on that occasion was used to represent a zero moisture deficit through the profile. This value was subtracted from the corrected total weekly counts through the season to give an estimate of the moisture deficit, converted to millimetres. Soil moisture deficits under grass were also calculated using meteorological variables and different 'models'. These were:-

- a. '50, 50, 25 mm model' using a potential transpiration figure derived from weekly sunshine recorded at Long Ashton Research Station. (See MAFF Technical Bulletin 16 for method.)
- b. '50, 50, 25 mm model' together with a weekly potential transpiration figure issued by the Meteorological Office at Bracknell on a grid square basis for the UK.
- c. A 3.0 inch (76.2 mm) root constant model, as described in Hydrological Memorandum No 38 and the Long Ashton calculated potential transpiration figure.
- d. A 3.0 inch (76.2 mm) root constant model using the grid square potential transpiration.
- e. A 3.8 inch (96.5 mm) root constant model (as described in Hydrological Memorandum No 38), with the grid square potential transpiration.
- f. An unrestricted water supply model using the grid square potential transpiration.

An albedo correction factor was applied to all of the computer derived grid square data to obtain potential transpiration over grassland.

FH2B

TABLE 1

TABLE SHOWING MOISTURE DEFICITS UNDER GRASSLAND AS COMPUTED USING VARIOUS "METEOROLOGICAL MODELS"
AND THE INTERPOLATION OF NEUTRON PROBE COUNTS

Date	Neutron Probe	50, 50, 25 model Long Ashton PT	50, 50, 25 model Grid Square PT	3 inch Model Long Ashton PT	3 inch Model Grid Square PT	3.8 inch Model Grid Square PT	Unrestricted Model Grid Square PT
5/4	0	a 0	b 0	c 0	d 0	e 0	f 0
12/4	6	6	8	6	8	8	8
20/4	26	19	22	19	22	22	22
26/4	14	13	18	13	18	18	18
10/5	- 9	2	2	2	2	2	2
17/5	6	6	6	6	6	6	6
24/5	38	32	34	32	34	34	34
31/5	66	53	55	56	59	59	59
14/6	43	14	16	27	30	30	30
21/6	31	22	24	35	38	38	38
28/6	51	40	40	53	54	54	54
6/7	77	64	67	78	83	83	83
12/7	99	75	78	98	101	104	104
20/7	105	82	85	105	107	118	119
27/7	120	90	93	110	112	126	135
4/8	137	101	102	113	113	133	164
10/8	141	104	105	114	115	134	176
17/8	124	76	78	84	84	103	162
24/8	77	28	30	36	36	55	114
31/8	35	1	1	9	7	26	85
7/9	40	8	6	16	12	31	90
14/9	47	18	17	26	23	44	101
20/9	56	28	25	36	32	52	109

RESULTS

The values derived from the 6 methods are tabulated in Table 1. By comparing columns (a) with (b) and (c) with (d) it can be seen that the differences in soil moisture deficit produced by the different methods of calculating the potential transpiration are negligible. A 't' test was conducted on the 2 sets of potential transpiration figures ie. those calculated from Long Ashton sunshine data and the corrected grid square data. The difference was not significant.

The differences on calculated soil moisture deficit produced by the different root models are however, quite large and are shown graphically in figure 2. The agreement between the neutron probe measurements and the 3.8 inch (96.5 mm) root constant model is generally very good. Three noteworthy differences occurred during the period of the readings.

On the 10 May the neutron probe indicated that the soil was about 9 mm above field capacity after a wet period. This excess appeared to drain through the profile during the following week.

A more serious difference occurred during June. The neutron probe showed a decrease in soil moisture deficit during the week 14 to 21 June, whilst the meteorological measurement predicted an increase in soil moisture deficit. No satisfactory explanation can be suggested for this discrepancy.

During a period of very wet weather in August, a large difference of 22 mm occurred. Some of the water probably drained through the profile, beyond the range of the neutron probe.

As neutron probe readings were taken at different depths through the soil profile an analysis was done to show the change in moisture content through the different layers. This is shown in figure 3. A daily plot of rainfall as recorded in a nearby rain gauge, together with the potential transpiration between neutron probe recordings are also shown. The rate of movement of rainwater through the profile shows considerable variations.

Late April, early May rainfall quickly reduced the near surface deficits to near zero, but had little effect at depth for nearly a week. Similarly rainfall between 31 May and 14 June decreased soil moisture deficits in the top 2 layers while deficits in the lower layers increased. During the following week deficits decreased in the lower layers indicating slow drainage through the profile.

Conversely when the soil was very dry through the profile in early August the heavy rains which fell during the third week rapidly percolated through the cracks and reduced the deficit in all the layers. This is shown by the neutron probe soundings made 0900 and 1530 GMT on the 17 August Table 2. Rainfall as recorded at 17/0900 was 32 mm, and a further 44 mm had fallen by 1530.

TABLE 2

Depth Zone Cm	Moisture content by volume %	
	0900	1530
0-12	16.1	18.9
12-22	20.5	22.7
22-32	26.2	31.5
32-42	26.7	31.6
42-52	27.8	33.5
52-62	36.2	38.6
62-72	43.1	44.4

CONCLUSIONS

The agreement between soil moisture deficits under grass calculated from neutron probe measurements and from meteorological data is good until transpiration falls below the potential rate in either the model or the sward. Agreement is then very dependent on the water extraction model used. At Westbury-on-Trym in 1977 use of a 3.8 inch (96.5 mm) root constant (as described in Hydrological Memorandum No 38) gave the closest agreement with the neutron probe measurements but further work on this and other sites will be required before such a model could be generally adopted for the calculation of soil moisture deficits under well established grass. The use of regular neutron probe soundings together with meteorological data could provide agronomists with information on the zones from which plants extract water throughout a season, and drainage engineers with percolation rates under different soil moisture conditions.

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WMO Technical note No 97

MAFF Technical Bulletin 16

Any comments or suggestions on this paper should be referred to the authors.

METEOROLOGICAL OFFICE
BRISTOL
September 1977

BRISTOL MAFF REGIONAL OFFICE

METEOROLOGICAL SITE

SWARD COMPOSITION SEPTEMBER 1977

	Per cent ground cover
Perennial ryegrass	29
Agrostis (mainly tenuis)	32
Yorkshire fog	14
Fine-leaved fescue (mainly <i>F. rubra</i>)	8
Daisy	16
Woodrush	1
	100

Also other species which did not fall within the quadrats, cocksfoot, yarrow, yellow-flowered compositae and others.

ESTIMATION OF THE CORRECTIONS REQUIRED WHEN THE MODEL 225 WALLINGFORD SOIL MOISTURE PROBE IS USED TO MEASURE SOIL WATER AT SHALLOW DEPTHS

1. INTRODUCTION

When the neutron probe is used with the source close to the soil surface, the slow neutrons counted come partly from the soil water and partly from the polypropylene shield resting on the soil surface. A simplified theory of the distribution of slow neutron production is used to calculate the contribution to the count from the shield and the factor by which the reduced count must be multiplied to obtain an estimate of the water content of the soil.

2. ESTIMATION OF THE SLOW NEUTRON COUNT FROM A CYLINDER OF MATERIAL

The polypropylene shield is in the form of a cylinder and in normal use the neutron probe is lowered into an access tube in the ground. It is therefore, convenient to work in cylindrical coordinates with the source of fast neutrons and the detector of slow neutrons at the origin. Figure A1 shows the configuration assumed.

If the source emits N fast neutrons per second then the bombardment (B) per unit area distance l from the source is

$$B = \frac{N}{4\pi l^2} \quad \text{neutrons per second} \dots\dots\dots (1)$$

This relationship is exact only if there is no loss of fast neutrons.

A small volume element δV receiving a fast neutron bombardment B , becomes a source of slow neutrons with emission rate $\propto B\delta V$ neutrons per second, where $\propto$ depends mainly on the number of hydrogen atoms per unit volume. If the slow neutrons are emitted equally in all directions the number of slow neutrons received per unit area of the detector near the origin is:-

$$C = \frac{\propto B\delta V}{4\pi l^2} = \frac{\propto N\delta V}{4^2\pi^2 l^4} = \frac{\propto N r \delta r \delta z \delta \phi}{4^2\pi^2 (r^2+z^2)^2} \dots\dots\dots (2)$$

Where δV is expressed in cylindrical coordinates.

Integrating over the volume of the hollow cylinder shown in figure A1 gives:-

$$\text{Count per second of slow neutrons} = C = \int_{r=R_1}^{R_2} \int_{z=Z_1}^{Z_2} \int_{\phi=0}^{2\pi} \frac{\propto N r dr dz d\phi}{4^2\pi^2 (r^2+z^2)^2} \dots\dots\dots (3)$$

$$\text{i.e. } C = \frac{\propto N}{16\pi} \left[\frac{1}{R_1} \tan^{-1}\left(\frac{Z_2}{R_1}\right) - \frac{1}{R_2} \tan^{-1}\left(\frac{Z_2}{R_2}\right) - \frac{1}{R_1} \tan^{-1}\left(\frac{Z_1}{R_1}\right) + \frac{1}{R_2} \tan^{-1}\left(\frac{Z_1}{R_2}\right) \right] \dots\dots\dots (4)$$

If $Z_1 \rightarrow -\infty$, $Z_2 \rightarrow +\infty$ and $R_2 \rightarrow \infty$

$$C \rightarrow \frac{\propto N}{16 R_1} \dots\dots\dots (5)$$

Since N and R_1 are constants for a given probe and sampling tube the neutron count in an infinite volume of soil is directly proportional to α and therefore, in most soils to the volume water content.

3. EVALUATION OF CONSTANTS IN THE SLOW NEUTRON COUNT EQUATION

Equation (4) is evaluated for 2 'reference' situations of the probe to determine the value of the constants $\alpha_w N$ for water and $\alpha_p N$ for polypropylene. The values are checked by comparing calculated counts with observations in two situations in which there are both water and polypropylene within range of the probe.

a. Count from probe in sampling tube in deep water

$$\begin{aligned} \alpha &= \alpha_w & C &= \frac{\alpha_w N}{16 \times 2.25} \\ R_1 &= 2.25 \text{ cm} \\ R_2 &= \infty \\ Z_1 &= -\infty & \text{Observed count} &= 1160 \text{ per sec} \\ Z_2 &= +\infty & \therefore \alpha_w N &\approx 41760 \end{aligned}$$

b. Count with probe in shield suspended in air

$$\begin{aligned} R_1 &= 2.0 \text{ cm} & C &= \frac{\alpha_p N}{16\pi} \left[\frac{1}{2} \tan^{-1} \left(\frac{4.5}{2} \right) - \frac{1}{8} \tan^{-1} \left(\frac{4.5}{8} \right) - \frac{1}{2} \tan^{-1} \left(\frac{-12}{2} \right) + \frac{1}{8} \tan^{-1} \left(\frac{-12}{8} \right) \right] \\ R_2 &= 8.0 \text{ cm} \\ Z_1 &= -12 \text{ cm} & &= \frac{\alpha_p N}{16} \times 0.3474 \\ Z_2 &= 4.5 \text{ cm} & \text{Observed count was } 652 & \therefore \alpha_p N \approx 30029 \end{aligned}$$

c. Count with probe in shield suspended in water

For the probe in deep water without a sampling tube.

$R_1 = 2.0 \text{ cm}$ The count expected would be; from equation (5)

$$1160 \times \frac{2.25}{2.0} = 1305 \text{ cps}$$

The count from the water that has the volume and shape of the shield is shield count in air $\times \alpha_w / \alpha_p$

$$= 652 \times 41760 / 30029 = 907 \text{ cps}$$

The count from the water surrounding the shield is thus

$$1305 - 907 = 398 \text{ cps}$$

The count from the shield is 652 cps

Total estimated count from shield in water 1050 cps

Observed count from shield in water 995 cps

- d. Count with probe 6 cm in water without a sampling tube and the base of the shield on the water surface

Count from water $\alpha = \alpha_w$, $R_1 = 2.0$ cm, $R_2 = \infty$, $Z_1 = -\infty$, $Z_2 = 6$ cm

From (4) $C = 1172$ cps

Count from shield $\alpha = \alpha_p$, $R_1 = 2.0$ cm, $R_2 = 8$ cm, $Z_1 = 6$ cm, $Z_2 = 22.5$ cm

From (4) $C = 26$ cps

Total calculated count = $1172 + 26 = 1198$ cps

Observed count = 1215 cps

The agreement between calculation and observation although not complete, is good enough for the present purpose.

4. EVALUATION OF THE CORRECTIONS REQUIRED WHEN THE PROBE IS AT DEPTH 'd' IN SOIL

- a. Count from the shield (Cs)

$\alpha = \alpha_p$, $R_1 = 2.0$ cm, $R_2 = 8.0$ cm, $Z_2 = 16.5 + d$ cm, $Z_1 = d$ cm

Substitution of these values in equation (4) gives

TABLE 1

d (cm)	0	2	3	4	5	6	7	10	14	18
Cs cps	350	134	84	55	37	26	18	8	3	1

- b. Count from the soil water

When the neutron source is at depth 'd' below the soil surface $\alpha = \alpha_w \theta$ where θ is the soil water content by volume.

$R_1 = 2.25$ cm, $R_2 = \infty$, $Z_1 = -\infty$, $Z_2 = d$ cm

From (4) the slow neutron count from the soil water C_{sw}^1 is given by

$$C_{sw}^1 = \frac{N \alpha_w \theta}{16 \pi} \times \frac{1}{2.25} \left[\tan^{-1} \left(\frac{d}{(2.25)} \right) + \frac{\pi}{2} \right] \text{ cps} \dots\dots\dots (5)$$

If the probe were in an infinite volume of soil with the same water content the count would be:-

$$C_{sw} = \frac{N \alpha_w \theta}{16 \times 2.25} \text{ cps}$$

$$\therefore \frac{C_{sw}}{C_{sw}^1} = \frac{\pi}{\frac{\pi}{2} + \tan^{-1} \left(\frac{d}{(2.25)} \right)} \dots\dots\dots (6)$$

Observations by Long and French (1967) have shown that at 30% soil moisture a neutron probe at a depth of 25 cm indicated more than 99% of the true moisture content. If it is assumed that the probe indicates the full moisture content at 25 cms and below then a better estimate of the ratio.

$$\frac{C_{sw}}{C_{sw}^1} \text{ is } \frac{2 \tan^{-1} \left(\frac{25}{(2.25)} \right)}{\tan^{-1} \left(\frac{25}{(2.25)} \right) + \tan^{-1} \left(\frac{d}{(2.25)} \right)} \dots\dots\dots (7)$$

Evaluation of (7) gives:-

TABLE 2

d (cms)	0	2	3	4	5	6	7	10	14	18
C_{sw}/C_{sw}^1	2.000	1.342	1.230	1.167	1.127	1.100	1.081	1.047	1.024	1.012

To correct a neutron probe reading near the surface subtract the shield count C_s for the appropriate depth and multiply the result by the factor C_{sw}/C_{sw}^1 . This gives an estimate of the count that would have been obtained in an infinite volume of soil with the same water content.

FIGURE I

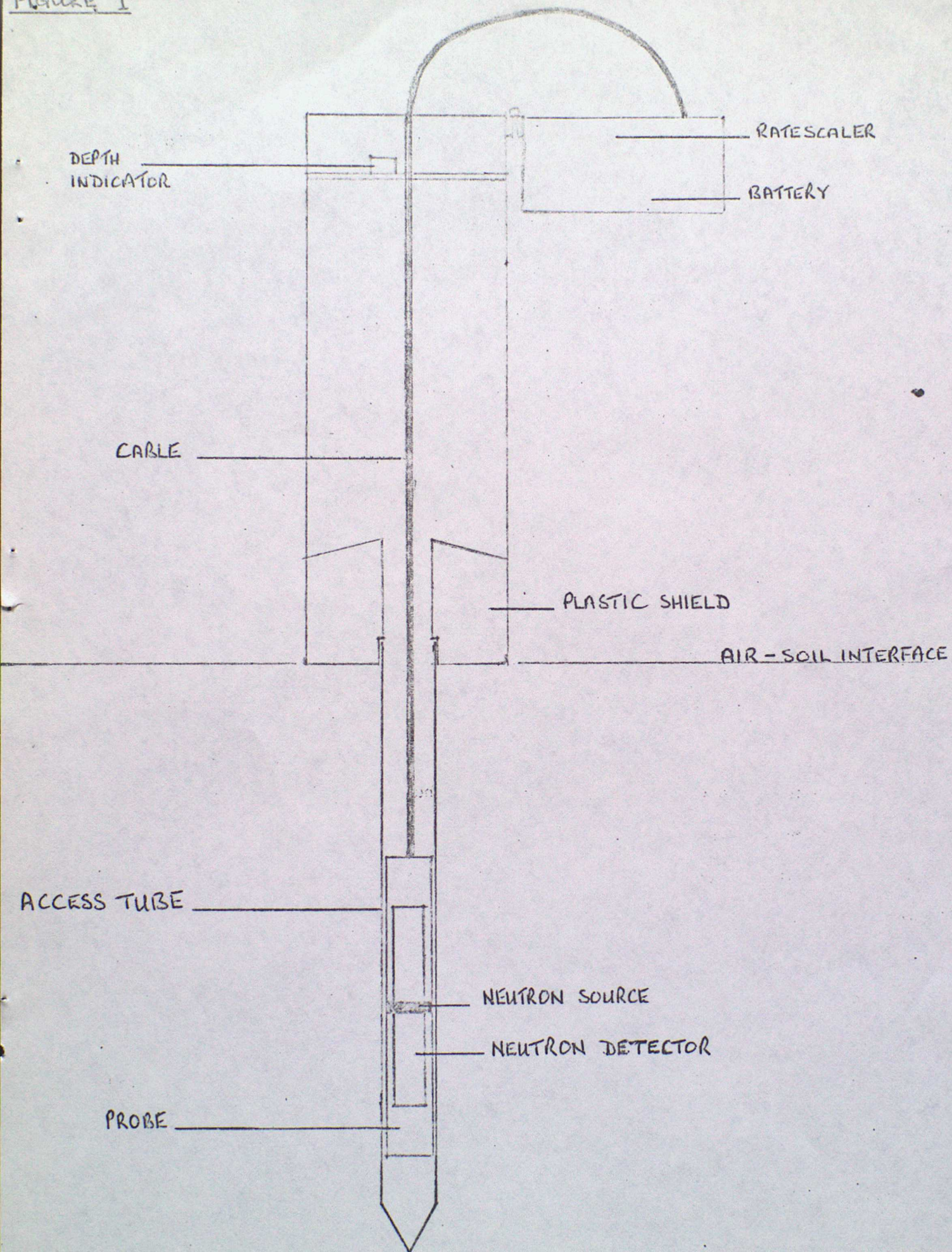
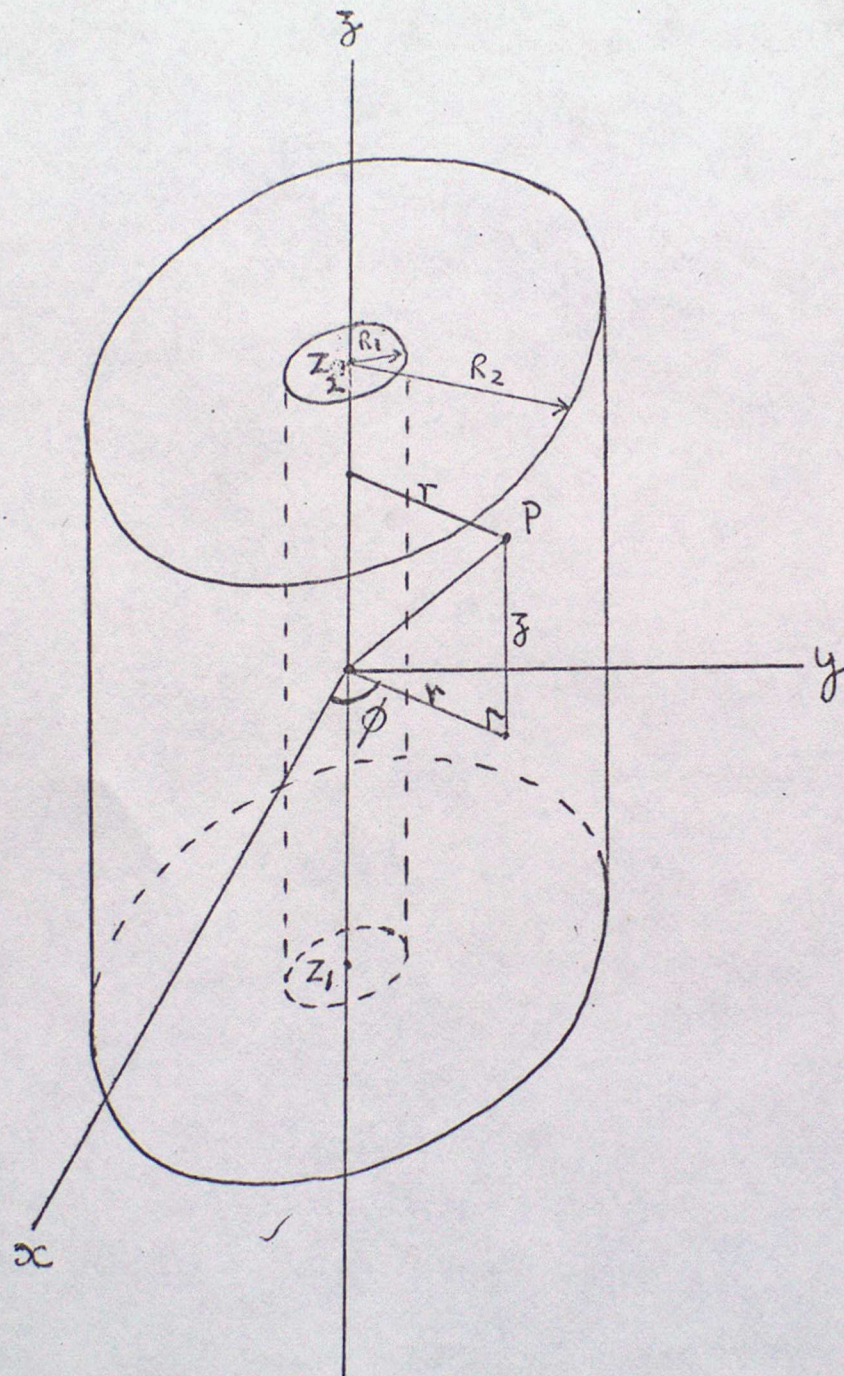


Figure A1



Coordinate system for the calculation of the slow neutron count.

FIGURE 2

A COMPARISON BETWEEN MOISTURE DEFICITS UNDER GRASSLAND USING VARIOUS
'METEOROLOGICAL MODELS' AND INTERPOLATED NEUTRON PROBE COUNTS

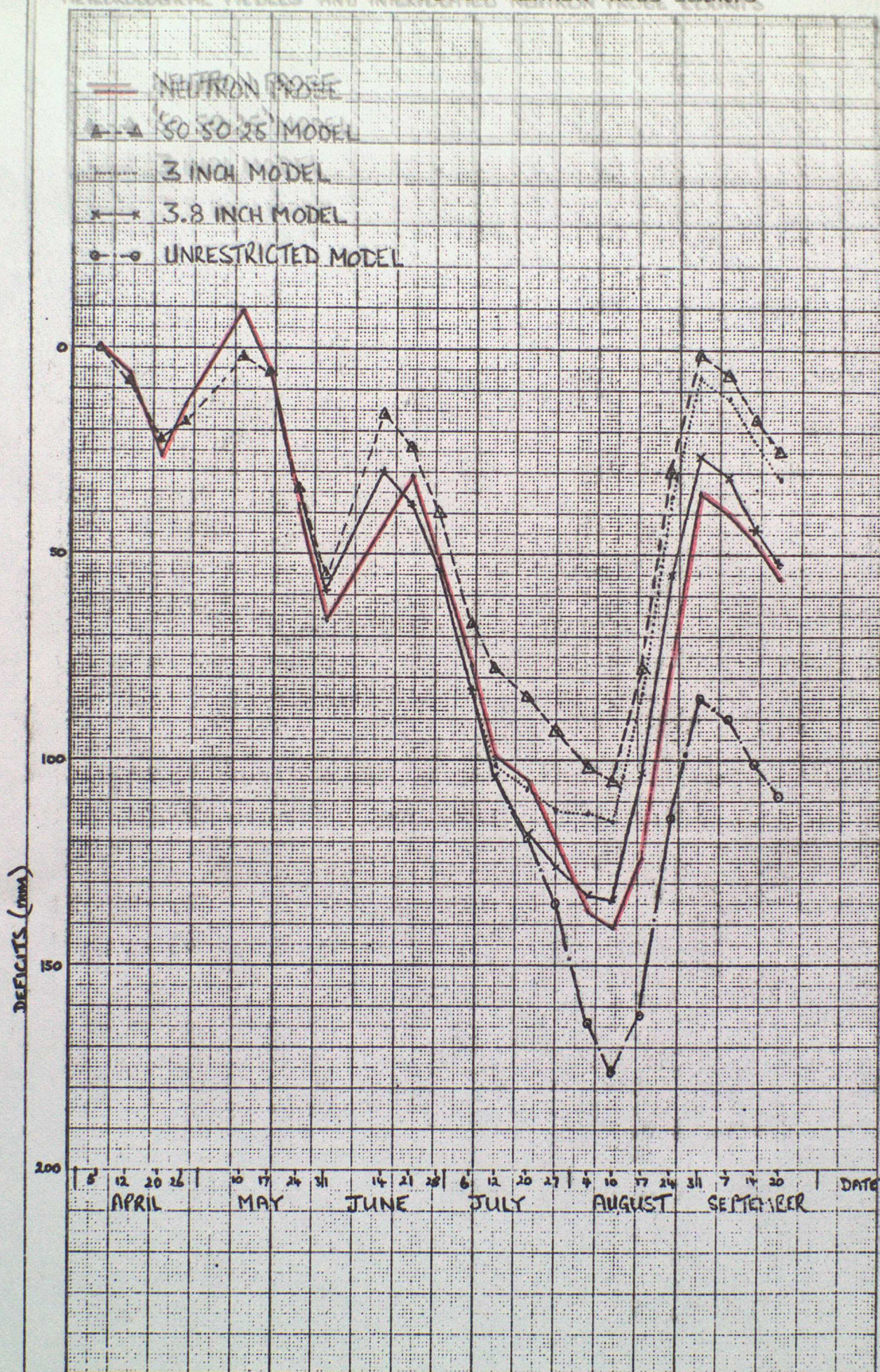


FIGURE 3

BAR CHART SHOWING DAILY RAINFALL TOTALS, WEEKLY GRID SQUARE POTENTIAL TRANSPIRATION, AND MOISTURE DEPARTURES FROM FIELD CAPACITY AT NEUTRON PROBE RECORDING DEPTHS

